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C o n t e n t s

VEGETABLE SEED TREATMENT/1

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From the extension standpoint, vegetable-seed treatment offers a simple and often spectacular approach to the farmer. It can be used to demonstrate in a simplified manner most of the accepted methods of disease control except immunization. The hot-water treatment of cabbage seed will serve to eradicate Phoma lingam and Bacterium campestre from the seed, and it will also serve to exclude them from an area. Perhaps more technically it will disinfect tissue where the organism (Phoma lingam) is already established and will disinfest tissue where the organism is merely riding along (Bacterium campestre).

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Likewise, the red-copper-oxide treatment on peas or spinach can be used to demonstrate control by protection from an organism attempting to break in from the environment. Protection of spinach or pea seed against inroads of Pythium involves many of the problems encountered with fungicides in the field in protecting an apple leaf against scab. There are the problems of coverage, retention of the initial deposit, tenacity in the face of leaching, and injury. In fact, at Geneva we are beginning to use seed protection as a rapid laboratory test of new foliage protectants.

Since the field of vegetable-seed treatment is so large, this paper will be limited to seed protection and more particularly to our own research on cuprous oxide. An effort will be made to indicate the extension possibilities and to suggest sources of difficulty in a successful demonstration and some of the elements necessary to explain such difficulties. It should be said at the outset that Dr. Charles Chupp has been a source of encouragement and cooperation in developing the problem of seed protection and its application to the farmers' needs.(4)/2

Significance of Seed Protection

Seed and seedling diseases appear to be on the increase in common with other plant diseases. The organisms causing these diseases apparently are becoming increasingly more widespread and more destructive. It would seem, therefore, that the applications of seed protection would likewise become more prevalent. As a matter of fact, many farmers do not realize that seed decay is so destructive on their farms until a seed-protection test is made there. Among the vegetables, spinach, wrinkled peas, and cucurbits perhaps respond best to seed protection, although almost any vegetable will respond under some climatic conditions.

There are three generic types of seed protectants, viz, organic mercury, zinc, and copper compounds. The organic mercuries stem back to Uspulun and its American prototype, Semesan, both of which are valuable, although rather expensive in comparison with the newer copper and zinc compounds. Semesan has a distinct place among the crucifers. Ceresan 2 percent and even New Improved Ceresan are being tested extensively as seed protectants. Both, however, are probably too volatile and contain too little mercury to become very widely adopted for the purpose of protection. Since mercury has a higher inherent toxicity than other metals, however, it requires more research.

The zinc oxides have been investigated extensively by Cook in Virginia (2, 3). He has found a zinc-oxide complex with outstanding dusting qualities (Vasco 4). Zinc oxide has received much attention also at Geneva (8). Zinc oxide is much the cheapest of any seed protectant. It is also nonirritating to workmen who tend large-scale treaters.

/2 Numbers in parentheses refer to Literature Cited, pages 31 and 32.

On the other hand, the inherent toxicity of the zinc is much less than that of copper or mercury, so that the sphere of usefulness of zinc is probably more limited. From data obtained by Kadow and Anderson (10), by Horsfall, and by Cook, it appears that zinc oxide is an outstanding possibility on crucifers which are injured by copper. The mercuries currently used are much more expensive than zinc oxide. Cook finds that zinc oxide "rings the bell" also as a spinach material in the Norfolk area. Zinc oxide is quite injurious to peas.

Red cuprous oxide dominates the field of vegetable-seed protection at present. It was developed at Geneva (7) as a result of work on copper-sulfate soak (5) and monohydrate dust (6). The reasons for this dominance are several:

It has remarkable sticking properties.
It penetrates seed wrinkles well.
It is nonvolatile in the soil and does not leach away.
It is effective at low dosage.
It gives itself a psychological boost because "it makes the seeds so pretty.
It is injurious to crucifers and certain legumes like lima beans. Otherwise, it seems to have a place on most any seed that is liable to preemergence damping-off. Even lima beans are treated commercially in Florida because the beneficial effects overbalance the injury.

Factors Affecting Seed Protection

When an extension man introduces a new treatment, he must be prepared to explain any subsequent trouble with the crop whether due to the new treatment or not. For that reason a discussion of the variables in seed protection is included here so that he may be as well informed as possible on the treatment.

The physics of the problem as regards dosage is important. Newcomers to seed protection tend, as we did, to use the materials in excess, screening off the residue. This may lead to erroneous conclusions when the treatment goes into practice, because it is not then economical to waste or even to rescreen the seeds. The surface area in any weight of seeds is a constant, and it can take up only so much dust. The area in 100 grams of spinach seeds is about 2500 cm.^{2}*, and in peas it is about 850 cm.^{2}*. Since the area of the spinach is about three times that of peas, it is an interesting fact that spinach requires about three times as much red cuprous oxide per unit of weight as peas require ($1\frac{1}{2}$ vs. $\frac{1}{2}$%). Materials should be compared, therefore, at the minimum coverage dosage.

It would seem that a smaller dosage could be made to go further by increasing the shaking time, but such has not been found experimentally.

If the minimum coverage dosage is used, then coverage capacity becomes important. Coverage capacity is a combination of dustability and retention. The material that floats best in the air of the treater covers

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* Square centimeter

wrinkles best, and the material that sticks the best will give the best protection. Likewise, particle size is important. The significant point is to cover the seed surface. The depth of coverage is unimportant. Other things being equal, the big particles cover the surface more deeply than do the smaller particles. Accordingly, more material is required. For instance, yellow cuprous oxide with particles 2u in diameter will give the same coverage at $\frac{1}{4}$ percent dosage on peas as red cuprous oxide with particles 4u in diameter will give with $\frac{1}{2}$ percent, and purple cuprous oxide with particles 6u in diameter will give with 1 percent dosage. Since, however, powders have a particle size population, an excess dosage of purple cuprous oxide will give equally as good protection as red cuprous oxide because the large particles are the ones screened off.

The chemistry of seed protectants is also of importance. The copper materials are toxic to certain seeds such as crucifers; the mercury materials are toxic to others such as tomatoes; and the zinc materials are toxic to still others such as peas. The percentage of active ingredient is a factor. This goes back primarily to coverage. The surface must be coated with a certain minimum amount of toxicant. If this surface is saturated with inert filler, the quantity of toxicant may be insufficient. For instance, in the one-half gram of 85 percent cuprous oxide required to give protection to 100 grams of peas, there is 0.43 grams of copper. If, say, a 15-percent copper compound is used, either the quantity of copper would be reduced to 0.08 grams, or the dosage required would be 2.5 percent. Moreover, the material should not be volatile so that it leaves the sphere of activity. Formalin, for instance, is worthless as a seed protectant. Likewise a soluble salt like bichloride of mercury is much less effective as a seed protectant than an insoluble salt like cuprous oxide. The compound must also have sufficient inherent toxicity. Cupric oxide is inferior to cuprous oxide on that account.

Soil temperature and soil moisture are very important in seed protection trials, although the state of knowledge on this subject is chaotic. Seeds vary in their temperature reactions to damping-off. Take two cool-weather crops like spinach and peas, and two warm-weather crops like cucumbers and lima beans. In the same soil the peas may damp-off best at 15° C., and the spinach at 25° C. The lima beans will damp-off fastest at 18° C., and the cucumbers at 25° C. The reasons for this are not clear, but it is a fair generalization that the plants will respond to treatment best at the temperature where they damp-off readily. Take subgermination temperatures for the two warm-weather plants - cucumbers, and lima beans. Cuprous oxide will carry the cucumbers through until the temperature is raised, but it will not carry the lima beans through.

Soil moisture is perhaps the chief limiting factor in preemergence damping-off. Generally, the disease increases as the moisture content increases, although the disease is reduced slightly as the moisture content approaches saturation, presumably because of lowered oxygen content. Likewise, as in the case of temperature, the percentage response to seed treatment increases as the moisture content increases. In a practical way, soil moisture is important because seeds decay most rapidly when rain falls

immediately after seeding. The best results from a seed-protection demonstration occur when rain follows immediately after seeding.

Inoculum potential enters the seed-protection picture very definitely. Inoculum potential is the disease-producing power of the soil. It is governed by the kind of organisms, by the amount of fungus, by the virulence of the fungus, by temperature, by moisture, by miscellaneous factors like packing, aeration, and pH. It can be measured by measuring the decay of nonprotected seeds. A curve showing the relation between seed-protective value and inoculum potential is J-shaped. The seed-protective value remains at a high level until inoculum potential reaches about 80. This means that the farmer attains maximum insurance with his seed protectant as long as nonprotected seeds do not decay more than 80 percent. If more than 80 percent of the nonprotected seeds decay, seed-protective value falls rapidly to 0. This means in practice that a seed-protection demonstration under either low or high inoculum potential conditions is likely to flop. It flops in one case because check seeds will not rot, and it flops in the other case because too many of them rot.

The effect of seed protection on different organisms is imperfectly known. We have found (9) that cuprous oxide gives protection against both Rhizoctonia and Pythium. Presumably it will give a certain amount of protection against any seed-decaying organism.

The stimulation from seed treatments has been tossed back and forth considerably between physiologists and pathologists. This probably means that it is a phenomenon in both fields. Undoubtedly, plants respond, in New York at least, to the nutritional aspects of the copper. This conclusion is based on other data than that coming solely from seed-protection research. On the other hand, the roots and rootlets of treated seedlings are much whiter than those on check plants. Certainly such plants can grow more rapidly than nontreated. In peas, the treated cotyledons survive decay longer in the soil than the nontreated cotyledons; as a result the seedlings have access to more growth materials.

Friction of Dusted Seeds

When the surfaces of seeds are coated with a dust, the interfacial friction is greatly increased. That means that the seeds do not slip readily over each other in being forced through a drill. In grain drills where the seeds are forced through narrow throats, this increased interfacial friction becomes important. Seeds are cracked, and drills may be broken. High moisture content of the seeds enhances the friction manyfold. At one time it was thought that the moisture caked the dust in the drill. This is a problem of considerable importance to the extension man. He does not wish to break any farmer's drill. Moreover, this phenomenon may influence the emergence data, for the dusted seeds do not sow so thickly as nondusted seeds. This difference may amount to 30 percent. If the seed protection does not amount to 30 percent, the check seeds will emerge thicker than the treated, and the accusation of injury might even be tied to the treatment. The addition of an amount of 325-mesh flake graphite (Dixon #0607)

equal to one-half the amount of seed protectant will suffice to reduce the friction to normal (1).

Seed Treaters

For small lots it is recommended that seeds be shaken in a closed container such as a fruit jar. For larger lots a barrel churn or Kirby's barrel treater is an ideal treater. One of the large canners in New York has devised a continuous rotating drum pea-seed treater capable of handling 110 bushels an hour. Most current wheat-seed treaters are unsatisfactory. They are designed to mix a volatile substance like ethyl-mercury phosphate with the seed. Complete coverage is unessential in this case. Seed protectants like red-copper oxide must be mixed completely. They require more tumbling and scrubbing together. It is particularly important not to use screw-type treaters. This type breaks the seed coats on peas.

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COTTONSEED TREATMENT /1

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The cotton plant is susceptible to attack by a number of micro-organisms that are known to be seed-borne. Judging from their general prevalence and the damage done to the cotton crop, perhaps the most important of these are Glomerella gossypii, cause of the boll rot commonly called anthracnose; Fusarium moniliforme, causal agent of pink boll rot; and Bacterium malvacearum, which produces the disease variously known as angular leaf spot, black arm, and bacterial boll-rot. Of less importance, generally, are Diplodia gossypina, cause of sooty boll rot, serious in some parts of the cotton-growing area, and Ascochyta gossypii, responsible for a necrosis of leaves, stems, and bolls of plants subjected to prolonged periods of high humidity. Rhizopus nigricans and Aspergillus niger occasionally cause boll rot, but are probably not significant as seed-borne parasites. There is evidence to indicate that the wilt fungus Fusarium vasinfectum is at times present in bolls and in seeds taken from diseased plants. A number of other fungi, particularly species of Alternaria, are found in open bolls where they cause stains, matting of the lint, and decay. The significance of these as seed-borne parasites is not well known, but is probably low.

The problem of cottonseed treatment has had for its immediate solution the improvement of stands by reduction of seed and seedling mortality. It has been a common experience of those who have observed germination of cotton after planting in the field that frequently less than 50 percent of the seed planted emerge as seedlings and even under very favorable conditions not more than 60 to 70 percent of the seed come up. This is true even though the same seed on the paper germinator may have shown germination of 90 percent or better. Considerable effort has been expended in determining the cause of this low emergence of apparently high-quality seed under ordinary planting conditions. In 1912 Barre (4)/2 showed that the

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/2 Numbers in parentheses refer to Literature Cited, pages 39 and 40.

anthracnose fungus, Glomerella gossypii, is present on and in many of the seeds taken from fields in which the disease occurs, and that this fungus causes a serious damping-off which may greatly reduce seedling emergence and subsequent survival. Woodruff in 1927 (18) showed that the pink boll-rot fungus, Fusarium moniliforme, is a seedling parasite which attacks the roots and causes considerable stunting of young plants. Bacterium malvacearum apparently does not damage seedlings by direct attack of the hypocotyls or roots; but primary cotyledonary lesions may enlarge, progress through the petiole, and finally involve the terminal bud and upper part of the stem in necrosis, thus killing the seedling. In addition to that group of seedling parasites which reach the seedling chiefly by virtue of being on the seed at plantingtime, there are other soil-inhabiting fungi capable of attacking cotton seedlings. Such are Pythium ultimum, Rhizoctonia solani, Sclerotium rolfsii, Fusarium vasinfectum, and Phytophthora parasitica. Nematodes of several species also are prevalent in diseased seedlings.

In recent years certain workers, notably Arndt, Ullstrup, and Miller, have attempted to determine by means of field surveys and isolations from diseased specimens the relative importance of the several organisms which cause death of cotton seedlings under average spring planting conditions. In 1935 Arndt (2) reported that Glomerella gossypii was the cause of heavy losses of cotton seedlings in South Carolina, and that Pythium was the cause of poor stands in certain fields. He also stated that 15 to 75 percent of the isolates from diseased hypocotyls were species of Fusarium and that over a period of 10 years Rhizoctonia had been found on less than 10 percent of the seedlings examined.

Microscopic examinations and culture-plate isolations from diseased seedlings collected by the writer in North Carolina in 1938 from one farm where treated and untreated seed had been planted showed that Glomerella gossypii was the predominating parasitic fungus on diseased seedlings from untreated seed not more than one planting season old. Of the seedlings of this group which did not show conidia of Glomerella gossypii by microscopic examination, approximately 17 percent yielded Glomerella gossypii, 35 percent Fusarium moniliforme, 40 percent Fusarium sp. and less than 10 percent Pythium or Rhizoctonia when plated out on agar media. From diseased seedlings growing from treated seed, Fusarium, Pythium, Rhizoctonia, and Glomerella gossypii were obtained more frequently than other forms. Since the Fusaria other than Fusarium moniliforme were found to be nonpathogenic in inoculation trials, it is believed that Pythium, Rhizoctonia and Glomerella gossypii, named in descending order of prevalence, are the chief causes of seedling mortality when treated (delinted, Ceresan) seed are planted. The results of earlier isolations made by the writer in 1935 and 1937 place these fungi in essentially the same order of importance.

Miller (15) and Ullstrup have made an important contribution to our knowledge of the relative significance of the several cotton-seedling parasites. Isolations were made by Ullstrup from samples of diseased seedlings collected in 1938 by Miller and others in the States of Virginia, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Tennessee, Louisiana, and Texas. Glomerella gossypii was recovered from 283 out of a

total of 344 samples examined. It was the predominating organism in 240 of the samples. It was found more times than any other single fungus in the samples from every State except Texas. Fusarium moniliforme took second rank, having been recovered from 239 of the 344 samples. It was the predominating form in 14 of the samples. Rhizoctonia solani occurred in 44 samples and was the predominating form in 11. Other fungi, Fusarium sp., Pythium sp., Diplodia gossypina, Rhizoctonia bataticola, Fusarium vasinfectum, Sclerotium rolfsii (named in order of prevalence) were found, but these were of minor importance. Obviously Glomerella gossypii holds first place as a seedling parasite of cotton, particularly in that part of the producing area east of the Mississippi River.

The importance of Glomerella gossypii as a seed-infesting parasite is again indicated by the results of tests of North Carolina seed of the 1936 crop (12). Thirty-five lots of seed obtained at random from farmers who were putting on seed-treatment demonstrations or who sent seed in to be germinated, were tested to determine the percentage of seed-borne infection. In only 4 of the 35 lots were less than 40 percent of the seed infected; all other lots had Glomerella gossypii on 40 percent or more of the seeds. The average percent of seedlings which showed the anthracnose disease upon germination was 65.9±, a standard error of 4.21. This is a surprisingly high degree of infestation and is a strong argument in favor of seed treatment before planting.

Arndt (1), has called attention to the presence of nematodes in diseased cotton seedlings in South Carolina and apparently he was at one time (1931) of the opinion that they were responsible for a considerable portion of the stand losses. More recently Arndt and Christie state (3) that the nematodes apparently are not factors of primary importance in the etiology of damping-off or sore-shin, but do increase stunting of plants by Fusarium moniliforme.

Seed Treatments: Materials, Methods, Results

Because of its fuzzy covering, cottonseed does not lend itself to treatment with aqueous solutions of disinfectants. The fuzz is not readily wetted by water, and air entrapped in its meshes occludes ordinary aqueous solutions. Treatments of this sort have given poor results and have been superseded by others, some of which will be discussed below.

Acid Delinting

Rolfs (16) in 1915 and Faulwetter (10) in 1919 showed that dissolving the fuzzy covering of cottonseed with sulphuric acid greatly reduced or eliminated incidence of angular leaf-spot on cotton seedlings. The dissolution of fuzz and charring of the seed coat destroy fungi and bacteria that may be on the surface of the seed. Thus acid-delinted seed are free or practically free of surface-borne parasitic organisms and therefore usually experience, except under special weather conditions, lower seedling mortality in germination than similar lots of untreated fuzzy seed. Chester (8) in 1938 found that floating of the light defective seeds in washing the

acid-delinted seed removes practically all the seed infected internally. In addition to this, acid-delinted seed has other advantages such as more accurate dropping from the planter so that little or no thinning may be necessary; more prompt emergence when planted in dry soil; and fewer seed required because of lower seedling mortality resulting from comparative freedom from seed-borne parasites. However, in spite of these apparent advantages, use of acid-delinted seed has not become a general practice with farmers, nor has it been generally recommended by plant pathologists and agronomists. If cold, wet weather follows immediately after planting, acid-delinted seed frequently comes up to a poorer stand than undelinted seed. This is especially likely to happen when the seed used for delinting is free or practically free of such organisms as Glomerella gossypii and Fusarium moniliforme. Brown (6) has shown that the poor germination sometimes obtained from acid-delinted seed is conditioned by the low air-supply accessible to the delinted seed in wet soil compared with that available to undelinted seed. The latter holds a sufficient supply of air in its fuzzy covering to enable germination to proceed in soil from which most of the air has been occluded by water, while delinted seed, deprived as it is of this reservoir of air, germinates poorly in wet soils. Brown suggests that better stands from delinted seed may be obtained from more shallow planting in the heavier soils.

Other obstacles to general adoption of the practice of planting acid-delinted seed have been the difficulty of obtaining concentrated acid at a reasonable price and the hesitancy of growers to take up an operation involving the use of a strongly corrosive chemical like sulphuric acid. Brown and Gibson (7) in 1925 contributed somewhat to the solution of this situation by working out anddescribing a machine for delinting seed with acid on a commercial scale. Recently (1938) Hancock (11) published details of construction and operation of a simple machine adapted to the needs of the individual farmer. The simplicity and low cost of this machine, which can be used not only for delinting but also for dusting seed should appeal to the farmer interested in cottonseed treatment.

Heat Treatments

Because of the difficulties and disadvantages incident to the use of sulphuric acid as a seed-treatment material, attempts have been made to use heat as a sterilizing agent for cottonseed. Duggar and Cauthen (9) in 1910 and Barre and Aull (5) in 1914 adapted the Jensen hot-water method to the treatment of cottonseed. Barre and Aull found that both internal and external elements of Glomerella gossypii could be killed by a 15-minute immersion in water held at a temperature of 70° C. without serious impairment of germination. This method of treatment avoids certain of the difficulties and much of the expense incurred in delinting with sulphuric acid. In 1925 the writer (13) published details of a dry-air treatment which completely eliminates anthracnose, but the high temperatures and especially the length of time required for the complete elimination of internal infection make general adoption of the method unlikely. Since neither the hot-water nor the dry-heat treatments are now in use, further consideration will not be given them in this paper.

Dusting

With the demonstration of the effectiveness of dust treatments, particularly the organic mercury-dust preparations, in control of seed-borne diseases of cereal grains and corn, there came to pathologists interested in diseases of cotton, the hope that the same or similar materials might be beneficial in control of seed-borne diseases of that crop. The simplicity and ease of making the dust treatments was alluring. Pathologists in a number of cotton-growing States, notably Mississippi, North Carolina, and South Carolina, began experimenting with dust preparations about 1925 to 1927. The first trials with fungicidal dusts on cotton in North Carolina were made by the writer in 1927. Semesan, Semesan Jr., Bayer 100-x-5, and Bayer 154-x-5 were used. The results were not highly satisfactory, but did suggest that other preparations might be more beneficial. Accordingly in the ensuing years a number of mixtures, some prepared locally, others by commercial concerns, were tried. Some of these dust mixtures contained inorganic salts of fungicidal properties, others mercury in combination with phenol, cresol, ethyl, or other organic radicals. Many of these preparations were found to increase seedling emergence and survival to a greater or less extent. After a few years, the preparation containing ethyl mercury chloride, and now known by the trade name Ceresan was singled out as the one which seemed to give the most consistently beneficial results under average planting conditions. For example, in 1929 tests somewhat demonstrational in nature were run on 18 farms in North Carolina, using the farmers own seed. On 11 of the 18 farms, increases of stand occured ranging from 25 to more than 100 percent. On 5 farms, neither consistent increases nor decreases resulted. On 2 farms the treatment appeared to reduce the stand of seedlings. The reason for these apparent reductions could not be determined. In none of the numerous more carefully supervised experimental tests made since then has the writer observed clear-cut cases of injury from use of Ceresan, even when used considerably in excess of the rate usually recommended.

The generally beneficial results occurring from use of Ceresan on cotton is attested by reports of experiments in other States, notably South Carolina, Georgia, Mississippi, Arkansas, Louisiana, and Texas. Although a rather meager amount of detailed data has been published, such statements as can be gleaned from bulletins and annual reports of the experiment stations of these States indicate a general agreement among research workers as to the value of Ceresan in increasing emergence and survival of seedlings after planting.

Although Ceresan has come to be the most widely recommended preparation for cottonseed treatment, results obtained in North Carolina in several years' tests, beginning with 1931, have led the writer to the conclusion that the preparation containing 5 percent ethyl mercury phosphate and named New Improved Ceresan is fully equal to, if not actually superior to the regular 2 percent Ceresan as a seed-treatment material for cotton. Applied to cottonseed at such rates as give equal quantities of the active ingredient per seed, these preparations give approximately equal increases in seedling emergence and survival. The advantage, if any real difference

exists, appears to be in favor of New Improved Ceresan. Small-scale storage tests by the writer indicate no harm from storage of seed treated with either Ceresan or New Improved Ceresan as long as 81 days in airtight containers, or 1 year in paper bags in the laboratory. Use of New Improved Ceresan (the 5 percent ethyl mercury phosphate now on the market) has two advantages over use of the regular 2 percent Ceresan: 1. Since the per pound price of the two materials is the same, and half or less is required, the cost per bushel is reduced proportionally. 2. It is a convenience to the farmer to have a single preparation that can be used both for cottonseed and cereal-seed treatment. It is the writer's belief that New Improved Ceresan (5 percent ethyl mercury phosphate) should be adopted as the recommended seed-treatment preparation for cotton.

Another preparation now being marketed for cottonseed treatment is sold under the trade name Sanoseed. The analysis published on the containers states that the preparation contains as its active ingredient 2 percent ethynol mercury chloride, 2 percent (14 percent metallic mercury). In a test on Cecil sandy loam in North Carolina in 1930 this material definitely decreased the stand in an early planting (April 16), gave moderate increases at the normal planting date (May 2), and slight but insignificant decrease in a very late planting (Aug. 21), while Ceresan increased the stand at all dates. On Norfolk sandy-loam soil, decreases occurred at two dates of planting. In a test of a new sample at two dates of planting in 1938 on Norfolk fine sandy loam, Sanoseed increased the percentage of surviving seedlings by statistically significant amounts. These increases were, however, less than half those produced by Ceresan in the same test. In a planting on Cecil sandy loam, Sanoseed gave a highly significant stand increase, which was still somewhat less than that given by Ceresan. Sanoseed as now compounded does not appear to be so effective as Ceresan as a seed-treatment material for cotton.

Copper carbonate has long been used as a treatment for wheat-covered smut. More recently certain commercial preparations which contain copper or zinc as the active fungicidal agent have been found valuable for use with vegetable and flower seeds. These and numerous noncommercial preparations have been tested on cottonseed with rather indifferent results. Cuprocide (cuprous oxide) in field tests by the writer has usually increased the stand of seedlings above that of untreated seed, and in some few tests these increases have been greater than those produced by Ceresan. However, in most of the plantings made over a series of years increases from Ceresan have been decidedly superior to those from Cuprocide or other copper and zinc preparations. In greenhouse tests in sterile sand, Ceresan has always given uniformly better results than any of the copper and zinc preparations that have been tried.

Relative Merits of Delinting and Dusting

In delinting seed with sulphuric acid, the fungi and bacteria present on the seed surface are destroyed. Thus seed carrying parasitic organisms are freed of that part carried externally. It has been repeatedly observed in greenhouse and laboratory tests that seedlings from acid-delinted seed

develop much less of sore-shin due to Glomerella Gossypii than those from undelinted seed. Furthermore, numerous tests show that primary infection of cotton seedlings by Bacterium malvacearum when planted on new land are almost completely eliminated by acid delinting. Ceresan likewise destroys or prevents development of a very large part of the surface-borne load of parasitic organisms, but not so effectively as acid delinting. Although it sometimes happens as under conditions of very wet soil, that acid-delinted seed gives poorer stands of seedlings than undusted fuzzy seed, and somewhat more frequently lower stands than Ceresan-dusted fuzzy seed, delinted seed usually gives equal or somewhat better stands than Ceresan-dusted fuzzy seed. This superior performance of acid-delinted seed is thought to be due in part at least to more effective destruction or repression of surface-borne inoculum of Glomerella gossypii than is obtained by dusts such as Ceresan. This is apparently true also of control of primary infections by Bacterium malvacearum. The writer's observations indicate that Ceresan does greatly reduce primary cotyledonary infection by this bacterium, but the amount of reduction has not been equal to that reported by others who have made similar tests with delinted seed.

It cannot be expected that acid delinting should destroy internal infection, nor that it should give any protection to the seed against parasitic soil-inhabiting organisms. On the other hand, ethyl mercury chloride and ethyl mercury phosphate do seem to have some appreciable protective effect against soil-inhabiting fungi like Pythium and Rhizoctonia. The evidence for this is the fact that while delinting increases emergence and survival of seed infested with Glomerella gossypii, appreciable further improvement is obtained by application of Ceresan to the delinted seed. The results indicate that if acid-delinted seed are to be planted under other than favorable soil conditions, they should be dusted with some protective fungicidal preparation before planting. In fact the combination of the two seed treatments might be the better practice. It would, I believe, result in better survival of seedlings and greater freedom from diseases in the post-seedling stage than either treatment alone.

Economic Benefits From Seed Treatment

It has been largely the custom to measure the success of seed treatment of cotton in terms of increase in seedling emergence and survival on the assumption that such increases would be reflected in increased yields. However, increased seedling emergence and survival is not always followed by a significant increase of yield. This has been true of a number of experimental tests. One reason appears to be that experimental plantings have generally been made later than the early plantings made by farmers. In the writer's experience, significant yield differences between treated and untreated seed have always been associated with early planting. Another reason seems to lie in the fact that a basic seeding rate high enough to give a fair final stand under adverse weather conditions without thinning has usually been used in the experimental tests. The thinning operation removes many more plants from the treated rows and greatly reduces the difference between treated and untreated seed. Even when a statistically significant difference in stand is evident after thinning on treated and

untreated rows, the ability of cotton plants to compensate for thin stands by increased yield of individual plants tends to reduce yield differences between treated and untreated seed. With lower rates of seeding such as many growers use, emergence on untreated rows is inadequate for a complete stand, whereas that on treated rows is sufficient to give an approximately perfect stand on thinning. Thus final stand differences greater than can be compensated for by individual plant performance are obtained and are likely to be reflected in significant yield differences. If yields are depressed by nutritional deficiencies such as rust or by boll-weevil infestation, the differences between treated and untreated plots may become so small as to be insignificant.

The writer (14) has obtained in experimental tests yield increases ranging from nothing up to 294 lb. of seed cotton per acre as a result of dusting the seed before planting, but in most tests where the cotton has been picked, yield increases have not been so large. Shaw (17) in 143 result demonstrations using farmers' own seed, in plantings made on the farmers' planting date obtained average increase of seed cotton per acre, amounting to 247 lb. in 1936, and 267 lb. in 1937. Such increases, of course, give a handsome return for the small amount invested in seed treatment. It is the writer's belief that cotton-seed treatment constitutes cheap insurance for adequate stands and generally more than pays its cost in increased yields.

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RECENT DEVELOPMENTS AND FUTURE TRENDS IN CEREAL-SEED TREATMENT/1

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The situation with regard to seed treatment of cereals has been well summarized by R. W. Leukel (5)/2. In this paper he sketches the historical facts leading up to present-day methods, reviews the cereal diseases controlled by seed treatment, discusses fungicidal materials with special attention to the organic mercury dusts, points out the trend towards custom seed treating, touches on the probable action of seed disinfectants in influencing yields, and appends a list of 139 references. Therefore, all that remains for the purposes of the present summary is to add the contributions of the past 2 years, together with a few observations on trends and practical phases.

Benefits From Organic Mercury Dusts

The outstanding recent development in cereal-seed treatment seems to have been the widespread acceptance and increased use of the organic-mercury dusts. To quote from a recent U. S. Department of Agriculture circular (7), organic-mercury dusts "control the seed-borne smuts of wheat, oats, barley, rye, and sorghum, except the loose smut of wheat and the brown loose smut of barley. They control barley stripe, help to control seed decay and seedling blights of all five of these grains and also corn, and often benefit flax."

To this it might be added that they control the common smuts affecting millet and are useful in treating seeds of several species of grasses for the control of seed-borne diseases. Further study may show benefits to numerous other grass and forage crops.

In addition to their wide application and effectiveness, the organic-mercury dusts have advantages over other materials that have been used on cereals in that they do not wet the seed, the treatment is a dry one, the same chemicals can be used on all grain seed, they are readily available and economically, easily, and safely used.

The organic-mercury dusts are gradually being improved. This past year the compound Semesan Jr., recommended for use on seed corn has been improved by the addition to it of material that renders it less dusty and therefore better to work with. Manufacturers are attempting to improve other commercial mercury dusts in the same way. They have experimented with the addition of a tracer dye to the dusts in order to make treated seed more readily detectable and also with quantitative chemical tests to detect small amounts of disinfectant on seeds.

/1 Presented at the annual meeting of the American Phytopathological Society, Richmond, Va., December 28, 1938.
/2 Numbers in parentheses refer to Literature Cited, page 45.

Seed-treating Machines

The recent perfection of simple, low-cost, homemade, gravity-seed-dusting machines for farm use, such as the Minnesota Seed-Grain Treater described in the circular just referred to (7), makes for increased adoption of these newer seed-treating materials. The working plans for this treater have been widely copied and distributed in other States. Demonstration of the Minnesota treater offers a new approach to the old, ever-present, cereal-seed-treating, extension problem.

Manufacturers of commercial seed treaters have kept pace with developments so that suitable, large-capacity, accurate machines are available for applying the organic-mercury dusts.

Along with this development there has been a very considerable increase in treating by seedsmen and also custom treating, either at elevators, mills, and the like, or on the farm by itinerant, portable machines. In Richmond, where we are holding this meeting, there is a large seed company that has made it a practice to treat, unless otherwise specified, all of the cereal seed they sell, amounting to many thousands of bushels annually. They are using organic-mercury dust and applying it with modern, automatic equipment.

The portable seed-cleaning and seed-treating idea is growing each season. In Indiana there was an increase of 13 farm-to-farm machines this year, 35 being in operation in 1938 as compared with 22 in 1937. In spite of rather low morale on the part of growers because of low price and quality, the amount of wheat and oat seed treated increased 96 percent over 1937, with 156,697 bushels receiving the disinfectant. In Illinois 20 portables operated in 1938 and there are prospects for the purchase of several more for use during the 1939 season.

It appears therefore that with the introduction of the superior dust disinfectants along with practical equipment for applying them, together with commercial and custom treatment, a decided impetus is being put behind the cereal-seed-treating movement.

During the past few years, farmers and those engaged in scientific agriculture have begun to realize more fully the importance of combating seedling diseases and root rots of wheat and other cereals. We are also beginning to find out that there are numerous other seed-borne diseases of cereals, aside from the smuts, and that seed treatment is sometimes an aid in combating the seemingly increasing seedling disease and root-rot problem.

Tests With Organic Mercuries

Machacek and Greaney from Winnipeg reported at this meeting that several years' field tests have shown that organic-mercury-dust preparations are superior to other seed disinfectants for the control of seedling blight and root-rot of wheat in Manitoba, but that increases in yield are dependent

on seed or soil infested with pathogenic fungi. When clean seed is sown in noninfested soil, no increased yield results; in fact the yield usually seems to be depressed under those conditions.

Since the early 1920's when testing of the organic mercuries was in the early stages, numerous workers have reported increases in stands and yields of cereals from seed treatment. At first the theory was advanced that this may have been due to stimulation of growth activities of the seed, but this has given way to the theory that the increase is due to the killing of pathogenic organismson the seed and to protecting it from invasion by others from the soil.

Time will not permit a review of the many tests of the effects of organic mercuries on yield of cereals that have been made by investigators in the U. S. Department of Agriculture, and in Iowa, Illinois, Indiana, Minnesota, Wisconsin, and other States, as well as in Manitoba and other provinces of the Dominion of Canada. The Dominion of Canada has been especially active in this field of research. In 1927 Greaney and Bailey at Winnipeg (3) treated wheat, oats, and barley with liquid Semesan, planted it in Helminthosporium-infested soil and obtained an increased stand of more vigorous plants from the treated seed. In 1928 Simonds and Scott (8) of the Dominion Department of Agriculture, conducted seed-treatment experiments with Marquis wheat, Banner oats, and Hannchen barley to determine the value of such treatments against natural and artificial soil infection from Fusarium culmorum and Helminthosporium sativum. Four organic mercurials, three liquid and one dust, showed a distinct protective influence from attacks of these fungi by way of the soil. The dust they used increased emergence of seedlings in soil artificially infested with Fusarium from 62.6 percent to 96.3 percent in the case of wheat, and from 50.9 percent to 98.6 percent in the case of oats. In soil artificially infested with Helminthosporium, the dust hastened wheat emergence from 36.8 percent in the check to 87 percent in the treatment, and barley emergence from 54.3 percent in the check to 97 percent in the treatment.

In 1936, Stoa, Brentzel, and Higgins (9) of North Dakota reported that when the rust-shriveled spring wheat of the 1935 crop was treated with New Improved Ceresan, the average emergence of seedlings was increased by about 7 to 14 percent, the lighter samples giving the biggest increase. In 1936 also Leukel (4) making tests with shriveled spring-wheat seed of the previous crop obtained similar results. In the spring of 1936 numerous farm demonstrations showed at a glance the benefits from the use of the mercury-seed treatment.

Machacek and Greaney (6) reported this year that treatment of seed affected with "black point" or "kernel smudge," caused principally by species of Alternaria and Helminthosporium, with either ethyl mercury phosphate (New Improved Ceresan) or methyl mercury nitrate (Leytosan) may or may not increase the seed value depending on the organisms concerned. Greenhouse tests with black-point seed in 1932, 1933, and 1934 were inconclusive, as Alternaria was the dominant fungus. In 1935 and 1936, however, when Helminthosporium was active, both mercurial dusts increased seedling emergence, reduced root-rot and increased yields.

It is apparent, therefore, in small grains, as in corn, flax, and other crops, that increases in stands and yields may result from the use of the organic-mercury treatments depending on the seed and soil pathogens involved.

Seed Treatment With Auxins or Hormones

Another very interesting new development and one that has the possibilities of having a far-reaching effect on seed treatment, is the work with auxins or phytohormones by several investigators, notably N. H. Grace, chemist with the National Research Laboratories, Ottawa, Can. Grace (1) has found, as have others, that applying the hormones to seeds in liquid form often retards subsequent root growth, but if seeds are treated with the hormones adsorbed on a dust carrier, so that a small, gradual supply of active material is made available as the seed starts growth, a very marked increase in root and top growth may result.

Using a mixture of two parts indolylacetic acid and two parts naphthylacetic acid per million parts of wheat seed, adsorbed on a dust carrier, Grace increased root length at the end of 14 days' growth by 102 percent. Top growth was also greatly increased. Somewhat similar results were obtained with barley and soybeans.

In addition to indolylacetic and naphthylacetic acids and combinations, a number of other substances such as phenylacetic, propionic, and butyric acids and their salts were found to be active with seeds. Since the dust carrier may be the regularly used 5-percent ethyl-mercury-phosphate seed disinfectant used at the rate of $\frac{1}{2}$ ounce per bushel of grain seed, the combined seed treatment using both phytohormone and disinfectant fits into a standard farm practice and may have far-reaching possibilities.

Future Research in Cereal-Seed Treatment

Research in cereal-seed treatment during the next few years will probably trend toward a more accurate measurement of the effects of seed treatments on yields and an attempt to determine more exactly the reasons for fluctuating results. A more complete study of the organisms involved seems desirable as does also a study of soil and ecological conditions affecting their development. Efforts should be made toward further improvement of disinfectants being used, including a comparatively simple test to determine the efficiency of any job of treating. Research will also include the interesting field that has now been opened up in connection with phytohormones as related to seed disinfection.

Extension workers will continue their efforts to increase the use of dust disinfectants, particularly the organic mercuries. Field demonstrations will attempt to show the increased yields that are likely to accrue from the use of dust disinfectants. Emphasis will be placed on the need for using the right dosage and on the time of application, pointing out that treating too far in advance of sowing decreases protection against soil organisms and increases danger of seed injury, and that seeding

too soon after treating lessens effectiveness of the treatment. The Minnesota Seed-Grain Treater will be demonstrated and publicized, and commercial treatment as well as the conditioning of seed by portable cleaning and treating machines will be pushed.

Aside from the benefits accruing through increased yields and quality, the value of seed treatment as a means of preventing the dissemination of pathogens must be remembered. Thorough seed disinfection and protection may prevent the introduction and spread of pathogenic seed-borne organisms into the soil and/or throughout any given lot of seed. We know there are many physiologic races of seed-borne organisms, and that resistant varieties cannot be depended on entirely. Soils in the larger cereal-producing areas have been, and still are, fast becoming contaminated with root-rot fungi. New forms of plant pathogens are arising and being disseminated. Seed treatment is one way to slow down this introduction and spread.

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